



Petrographic and Provenance Study of Late Eocene – Late Oligocene Epoch Sediments of Three Wells from ‘X’ and ‘Y’ Fields, Central Depobelt, Niger Delta, Nigeria

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Abstract

The present study evaluates the petrographical characteristics of sandstone samples from ‘X’ and ‘Y’ fields located at the Central Niger depobelt province of the Niger Delta. The rationale for the petrographic study of these sediments is to decipher the mineralogical constituents, composition, provenance and as well as the source of the deposits in order to effect the understanding of the sediments. Framework grains are sand to silt-sized particles of mainly detrital origin. The common detrital grains analyzed from these sediments are Quartz (1.80-9.60%), K-Feldspar (2.70-7.20%), Plagioclase (1.40-8.50%), Muscovite (0.0-1.50%), lithic fragments (2.10-10.40%) and minor heavy minerals occurring as accessories. Among the main detrital framework grains, quartz constitutes the greatest percentage of the minerals. Petrographic study of these wells cutting samples showed that the analyzed sediments in wells - ‘B’, ‘D’ and ‘E’ were classified as quartz arenites, subarkosic and arkosic units based on their respective abundance minerals, pore-throats, cementation and other associated accessories. The textural and mineralogical maturity of the sandstone therefore implies that the sediments may have undergone more than one depositional cycle. However, the analyses of all the minerals in these sediments probably depict the provenance of igneous depositional setting. The modal analysis shows that, higher percentage of the sandstone samples belong to quartz arenites, as these points out to a continental provenance setting.

Keywords: Petrography, Provenance, Mineralogical constituents, Heavy mineral, Central Depobelt and Niger Delta.

Introduction

Sandstone deposits make up only about 25% of the stratigraphic record, but have received the most attention in the studies of sedimentary rocks.

However, there are basically two reasons for this. First, sandstones are easily studied because they contain sand sized grains that can easily be distinguished with a petrographic microscope.

Second, most of the world's oil and natural gas is found in sands or sandstones because of their generally high porosity and permeability properties. Conversely, oil and gas reserves in the Niger Delta sedimentary basin occurred mainly in the sandstone reservoir of the Agbada Formation (Evamy et al., 1978). Amajor, (1982), Lander et al, 2008 and Ingersoll and Suczek, (1979) documented that the composition of the sediments within this formation is principally made up of quartz minerals with other accessory minerals, thus compositional difference is thought to reflect the differences in provenance relief, distance of transport and depositional rates. Etu-Efeter, (1999) and Odigi, (1986) reported that compositional and geochemical analyses carried out on light minerals fraction of deposits from Niger Delta basin indicates that quartz is the most prevalent and dominant mineral with little proportion of rock fragments. They also added that mineral assemblage within this environment probably point to an igneous and /or metamorphic origin as heavy minerals such as Zircon, Topaz, Epidote, Haematite and Tourmaline show their presence. Vernik and Nur, (1992), Friedman and Sanders, (1978), Friedman, 1961 and Visser, (1969) divulged that the textural and mineralogical differences between grain-supported and matrix-supported lithologies are further stressed by their different sensitivity to fluid saturation effects. Relative volumes and maturity of deposited material in different sedimentary environments are considered with respect to their depositional settings (Hiatt and Kyser, 2000; Hartkamp et al., 1993). This has been demonstrated at different depositional environment and have been observed to exhibit different sediment maturity at a given point in time (Fig.1). However, this is realistic where the kinetic energy increases and is maintained in a given sedimentary environment. The degree of sorting and grain size will also increase, while detrital clay is winnowed and transported away from the site of deposition, textural maturity increases

and aquifer properties improved. The provenance area for these texturally and mineralogically mature sediments include the crystalline basement areas of Oban Massif and Cameroun basement granite which had undergone prolonged chemical weathering (Akaegbobi and Boboye, 1997; Nwajide and Reijers, 1996).

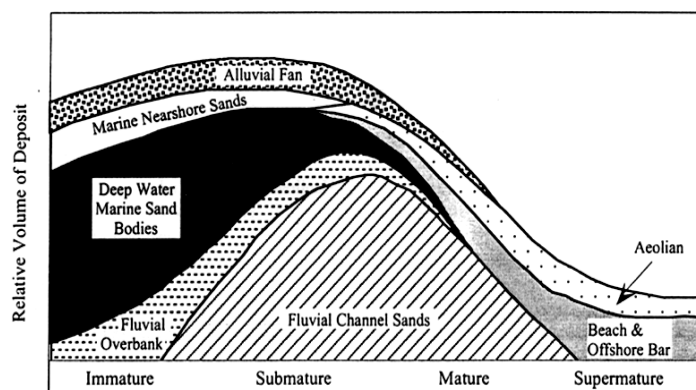


Fig.1. Relative volumes and maturity of deposited material in different sedimentary environments (After Hiatt and Kyser, 2000).

Due to the importance of potentials sandstone bodies as reservoir constituents for hydrocarbons, there is need for a comprehensive petrographical studies of these sedimentary deposits.

This study therefore addresses petrographical properties in the study wells and also explicates further understanding in terms of sediment maturity and their attributes within a stratigraphic framework. This however, will be used to identify the sediments depositional source leading to a better disposition of all untapped reservoir compartments in the five wells which will enhance further study of the adjoining fields for new discoveries.

Field Location and Geological Setting Niger Delta

All the wells and log motifs used in this study were obtained from Nigerian Agip Oil Company Limited in Port Harcourt. The study area of these two fields ('X' and 'Y') occupies about 616.79 acres in the onshore Niger Delta. The Fields location and the respective

well distances between the five study wells are shown in Fig. 2. These fields are pseudo-named 'X' and 'Y' for the purpose of confidentiality and are they located within Latitude: $5^{\circ} 20'N$, Longitude: $6^{\circ}40'E$. The fields are situated in the eastern part of Central Niger depobelt and in north eastern part of Bayelsa State of Nigeria. A total number of five wells were used in this research work, of which four of these wells ('A', 'B', 'C' and 'E') belong to 'X' Field while the remaining one, well ('D') belongs to Field 'Y'. The oil wells on the fields are located on elongated rollover anticline bounded to the north against a large east- west trending growth fault and to the east by north west-south trending fault.

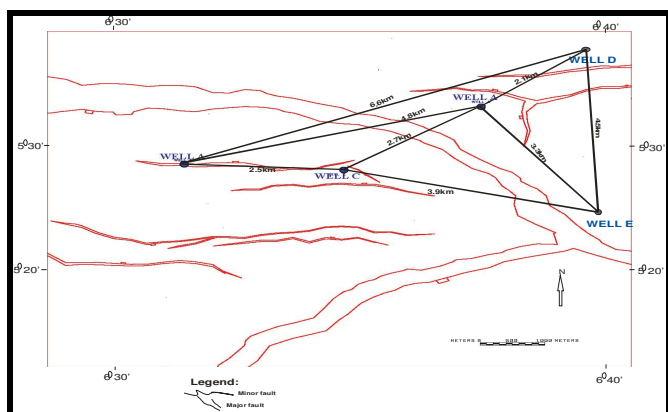


Fig.2. Wells location and their distances within the two Fields.

Niger delta basin is located within the Gulf of Guinea and covers an area of about 75,000km² and has an average sediment thickness of about 12,000m (Reijers, et al., 1997). The geologic evolution of the Niger Delta basin transcends and predates the Paleocene regressive clastic wedge that is conventionally ascribed to the delta (Frankl and Cordry, 1967; Short and Stauble 1967; Weber and Daukoru, 1975). It is connected to the tectonic setting of the southern Benue Trough, which is the Mega structure whose coastal and oceanward part lies the Niger Delta (Avbovbo, 1978), however, the Benue Trough is a NE - SW folded rift basin that runs

diagonally across Nigeria. It represents a failed arm of a triple junction associated with the opening of the Gulf of Guinea and the equatorial Atlantic in Aptian-Albian times when the equatorial part of Africa and South America began to separate (Benkhelil, 1987). The formation of the Niger delta basin began after second depositional cycle (Campanian-Maastrichtian) of Benue Trough that formed the proto-Niger Delta. The third and last depositional cycle of the southern Nigerian basin formed the Niger delta formations. According to Reijers (2011), the evolution of this basin was and is controlled by allocyclic and autocyclic processes. Autocyclic cycles result from natural redistribution of energy within a depositional system such as channel meandering or switching and delta avulsion. While allocyclic cycles results from changes in sedimentary system as a result of an external cause such as eustatic sea level change, tectonic basin subsidence and climate change. The combined effect of the two processes resulted in delta-wide sediment distribution and progradation of siliciclastic system over the pre-existing continental slope into the deep sea during the late Eocene and is still active today (Burke, 1972). According to Short and Stauble (1967), the stratigraphy of the Niger Delta can be divided into three major units. Ranging in age from Eocene to Holocene: (1) The Akata Formation, which includes at least 6500m (21,400ft) of marine clays with silty and sandy interbeds (Whiteman, 1982). (2) The Agbada Formation, which is characterized by paralic to marine coastal and fluvial-marine deposits mainly composed of sandstones and shale organized into coarsening-upward off-lap cycles (Weber, 1971). (3) The Benin Formation, which consists of continental and fluvial sands, gravel, and back swamp deposits of about 2500m (8250ft) thick (Reijers, 2011). Notable authors such as Ejedawe, 2012, Doust and Omatsola, 1990, Stacher, 1995, Frankly and Cordry, 1967 and Tuttle et al., 1999 showed that this three diachronous formations occur within the growth

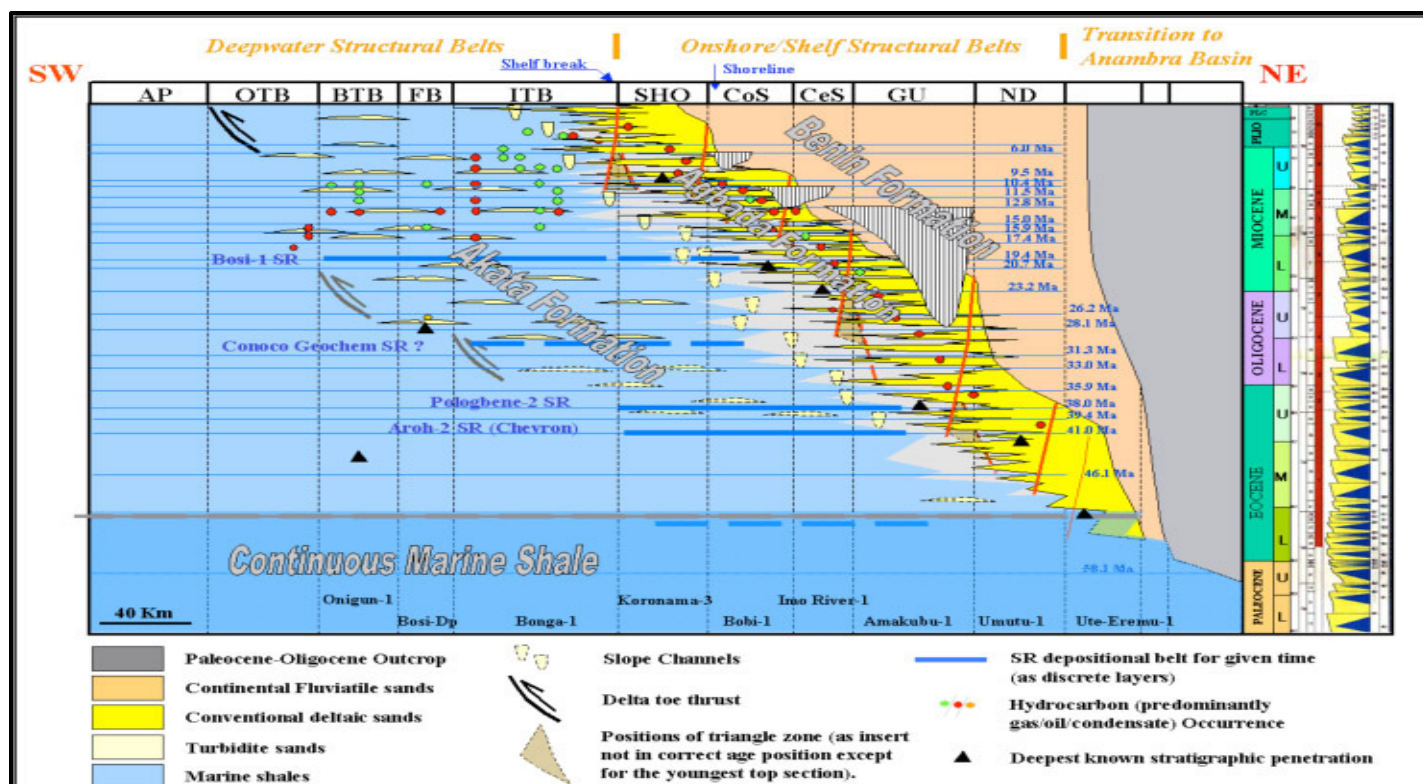


Fig.3. Stratigraphic column showing formations of the Niger Delta (After Ejedawe, 2012).

fault bounded sedimentary units called depobelts or depocenters that succeed each other in a southward direction (Fig. 3). The sedimentation in each depobelts shown in figure 4 was a function of rate of deposition and rate of subsidence with syn-sedimentary growth fault upsetting the balance (Evamy et al., 1978).

The growth faults are generated by rapid sedimentation and gravitational instability during the accumulation of Agbada deposits and continental Benin sands over mobile and under-compacted Akata prodelta shales. Lateral flowage and extrusion is also responsible for the diapiric structures on the continental slope of Niger delta (Reijers et al. 1997).

Materials and Methods

A total of nineteen (19) ditch cutting samples representing these three wells ('B', 'D' and 'E') were chosen for this exercise and the laboratory preparation of these samples was carried out in the Geology

Department, University of Calabar, Nigeria. The selection of the samples was done on the interval of the wells that show good reservoir sand bodies within the chosen horizons. These samples were prepared as thin sections for petrographic analysis of minerals. Ditch cutting samples were impregnated with hardener (araldite) and mounted on glass slides and were polished to the required thickness of 0.03mm, suitable for optical microscopy. Manual laboratory techniques were employed in the preparation of these thin sections for this study.

The following steps outlined were applied to these preparatory procedures; they are: nineteen ditch cutting samples were provided for this study. Each representative sample was sparsely mounted on a glass slide using epoxy resin with hardener and placed on a hot plate. Mounting jigs were used to hold the slide in place to reduce air bubbles for about 2 - 5 minutes and allowed to set. The slides were removed and kept to

cool at room temperature. The impregnated surface of the slide was then polished using 120 (coarse), 400 (medium), and 600 (finest) abrasives. Water was used as a solvent. The thickness of the mounted specimen was further reduced to minimum of 30 μ using adhesives as specified above. This required thickness was reached and determined by frequently observing the distinct first-order birefringent colours of common minerals such as quartz using the petrographic microscope. Each slide was labeled appropriately for petrographic study using an optical microscopy. The prepared slides were studied in plain and cross-polarized lights in order to identify the constituent minerals in the sediments and their percentage abundance. Photomicrographs of the thin sections (plain and cross-polarized lights) were conspicuously taken. Great care was taken at all times in the petrographic preparatory procedure because identification of the inherent minerals depends on the subtle rendition of the characteristic interference colours.

Petrographic Analysis

Sand and sandstone classification system of Pettijohn et al., 1987 which is based on quartz, feldspar and lithic grains contributions was adopted in this study (Fig. 4). It was observed that the sediments from the study wells exhibited good percentages of quartz arenites, subarkosic and arkosic arenites as their mineral constituents. These principal mineral constituents were recorded as percentages in all the analyzed intervals of the wells. The comparative techniques with the use of Michel-levy mineralogical interpretative chart were employed in this analysis. It was observed that some of the prepared thin sections analyzed contain iron minerals which were sometimes highly ferruginous in nature. They showed reddish brown to opaque colouration in plane polarized light (ppl) and are sometimes completely opaque in cross polarized light (cpl). It is reasonable however, to point

out here that the excellent nature of the photomicrographs obtained from these samples depend on the quality of illumination, focus, exposure and the nature of the samples/depths selected for this exercise. The analyzed intervals showed that quartz is the predominant mineral in almost all the samples/analysis undertaken. However, most of the samples studied were fine to medium and sometimes coarse grained with off to smoky-white in colour. A few quartz grains showed yellowish to brown colouration however, most of the quartz grains are subangular to sub-rounded. It is important to state here that the highly nature of the coarseness of the sediments resulted in the poor recovery of heavy minerals.

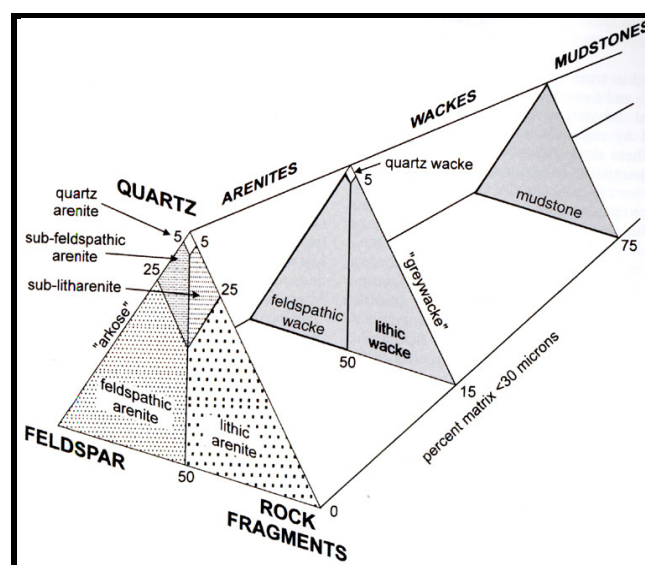


Fig.4. Sand and sandstone classification based on quartz, feldspar and lithic grains contributions (Pettijohn et al., 1987).

Results and Discussion

Sandstone found within the analysed interval depths were classified based on Pettijohn et al., 1987. These include; matrix (fine grained material that is associated with the sand grains), quartz, feldspar and rock fragments (sand grain that is made up crystal of

Table 1. Detrital modes of minerals in thin sections of Well -‘B’

Depth (m)	Quartz (%)	Plagioclase (%)	K-Feldspar (%)	Accessory minerals (%)	Staurolite (%)	Zircon (%)	Epidote (%)	Anthophyllite/ Enstatite (%)	Rock Fragment (%)
1900-2000	70	5	-	10-Tourmaline	-	5	10	-	-
2220-2240	80	-	-	5-Kyanite	-	-	10	5	-
2440-2478	85	5	-	5-Diopside	-	-	5	-	-
3270	75	5	-	5-Kyanite	-	-	5	10	-
3938	80	-	5	5-Serpentine/ Fayalite	-	-	5	-	5

Table 2. Detrital modes of minerals in thin sections of Well -‘D’

Depth (m)	Quartz (%)	Plagioclase (%)	K-Feldspar (%)	Accessory minerals (%)	Staurolite (%)	Zircon (%)	Epidote (%)	Anthophyllite/ Enstatite (%)	Rock Fragment (%)
2290-2320	80	5	-	5, Phlogopite	-	-	5	5	-
2530-2540	80	-	5	5, Kyanite/ Actinolite	-	5	5	-	-
2600-2620	80	-	-	5, Tourmaline	5	-	5	-	-
2810-2870	80	-	5	5, Diopside/ Serpentine	-	-	5	-	5
3000-3120	80	-		5, Apatite/ Kyanite	5		-	10	-
3300-3320	70	5	5	5, Tourmaline/ Andalusite	-	-	5	-	10
3825-3850	85	-	5	5, Kyanite	-	-	5	-	-
3960-4000	60	5	10	5, Kyanite	-	10	-	-	10

Table 3. Detrital modes of minerals in thin sections of Well - 'E'.

Depth (m)	Quartz (%)	Plagioclase (%)	K-Feldspar (%)	Accessory minerals (%)	Staurolite (%)	Zircon (%)	Epidote (%)	Anthophyllite/Enstatite (%)	Rock Fragment (%)
2200-2280	70	5	10	5Kyanite/Serpentine	-	-	10	-	-
2610-2655	80	-	5	5Actinolite	-	-	5	-	5
3010-3080	65	5	-	5Tourmaline	5	5	5	-	10
3370-3400	75	-	-	5Tourmaline/Kyanite	5	-	10	5	-
3900-3950	80	-	-	5Tourmaline	5	-	5	5	-
4110-4140	70	-	5	5Tourmaline/Diopside	-	-	5	-	15

two or more different minerals). The analyzed intervals of the wells ('B', 'D' and 'E') showed that quartz is the predominant mineral in almost all the samples. Most of the samples used in this study were observed to be fine to medium and sometimes coarse grained with dirty to smoky - white in colour and in some depths the sands are much cleaned. A few quartz grains showed yellowish to brown colour. Most of the quartz grains are sub-angular to sub-rounded in nature.

Mineralogically, in well-'B', five samples from 1900 – 3938m depth were analysed, the result showed that Quartz minerals with 78% predominates over the other minerals and was seconded by Plagioclase 3% and K-Feldspar minerals 1%. However other heavy minerals which occur within this depth are Epidote 7%, Anthophyllite/Enstatite 3% and Rock fragment 1% respectively. The accessory minerals in well-'B' was about 6% and these include heavy minerals such as Tourmaline, Kyanite, Diopside, Serpentine and Fayalite. Six samples from interval depth of 2290 –

3320m were analysed from well-'D', Quartz mineral was found to be 77.4%, Plagioclase 1.9% and K-Feldspar 3.4%. Associated heavy minerals within the interval depth are Epidote 3.8%, Staurolite 1.6%, Zircon 1.9%, Anthophyllite/Enstatite 2.5% and rock fragment 3.1%. Accessory minerals in well-'D' were observed to be about 9% and they include Phlogopite, Kyanite/Actinolite, Tourmaline, Diopside/Serpentine, Apatite/Kyanite and Tourmaline/Andalusite respectively. Minerals recovered from the six analysed interval depths of 2200 – 4140m in well-'E' divulged that quartz mineral predominates with 73.3%, K-Feldspar 3.3% and Plagioclase 1.7%. The encountered heavy minerals include Epidote 6.7%, Staurolite 2.5%, Anthophyllite/Enstatite 1.7% and Zircon 0.8%. Accessory minerals found within this depth are Tourmaline, Kyanite/Serpentine, Actinolite, Tourmaline/Kyanite and Tourmaline/Diopside making up of about 5% respectively.

Further petrofacies evaluations made from well- 'B', 'D' and 'E' sediments are as follows:

Unit - I: Quartz arenites

The quartz arenite unit in well - 'B' falls within 1900 - 2000m, 2220 - 2240m, 2440 - 2478m and 3270m. They are mainly quartz (mono and polycrystalline) minerals (Appendix 1, Plates 1 - 3) which are about 90% with minor amount of Plagioclase (5%) and K-Feldspar (5%). However, in the study well - 'D' (interval 2290 - 2320m, 2530 - 2540m and 2600 - 2620m) and as well as well - 'E' (interval 3370 - 3400m and 3900 - 3956m) they also showed peculiar characteristics of minerals which belongs to this group (quartz arenite). The sandstones are dominantly medium to coarse grained with no clay matrix. Cementation properties within the respective horizons are by quartz overgrowths. This unit is characterized by good sorting and may indicates good porosity with probably well connected pore throats of good reservoir quality. Other accessory minerals which occurred within these intervals include Zircon, Tourmaline, minor Kyanite, Staurolite, Enstatite, Anthophyllite, Epidote and Metamorphic rock fragments with relatively few and incessant occurrences of muscovite (clay) minerals were shown by sediments of well - 'B'. Wells - 'D' and 'E' also showed varying accessories which include the following; Phlogopite, Actinolite, Diopside, Andalusite and Serpentine (as in Tables 1,2&3 above).

Unit - II: Subarkosic

The subarkosic lithofacies units which occurred within the wells in this study area are predominantly made up of quartz minerals (70%), appreciable amounts of Microcline with K-Feldspars (15%) and Plagioclase feldspars (>15%). All the minerals analyzed for sediments in this unit are shown on Tables 2 & 3 above, Appendix 1, and Plates 4 - 6. These sand intervals (well - 'B' - 3938m; well - 'D' - 2530 - 2540m, 2810 - 2870m and 3825 - 3850m and well - 'E' - 2200 - 2280m, 2610 - 2655m and 4110 -

4140m) are very fine to fine grained, sometimes coarse grained which are moderately to well sorted, with somewhat subhedral grained due to wide spread of quartz over-growths. The included feldspar minerals within these depths also exhibited twinning structures (interval 2440 - 2478m of well - 'B') and opaque (dark) features signifying the presence of iron ores (interval 2610- 2655m of well - 'E') were observed under the cross polarized light. Cementing materials are chiefly made up of silica and carbonaceous materials with overgrowths. This unit has a good porosity and well-connected pore spaces within the grains.

Unit - III: Arkosic arenite

These units (Plates 7 - 9) comprises of quartz minerals (60%), Plagioclase (5%), K-Feldspar (10%) and clay fraction (15%). The siltstone sediments present within these horizons are very fine to fine grained with very high matrix materials. Cementation is dominantly by clay with minor overgrowth and occasioned fractured quartz grains. However, due to good shale percentage contents or occurrence within these intervals, their porosity properties may be slightly reduced. Minor accessories ranging from 5-10% occurred within these intervals include Tourmaline, Andalusite, Diopside, Serpentine and Kyanite (as in Table 3 above) with rock fragments. This unit only occurred in well - 'E' (interval 3010 - 3080m and 4110 - 4140m).

The mineralogical composition showed that quartz is the ubiquitous mineral with minor occurrences of K-Feldspar, Plagioclase and rock fragments. All the analyzed minerals observed from the sediments of the wells point to igneous and metamorphic sources with a little contribution and/or inference drawn from the presence of metamorphic rock fragments. The mineralogical maturity of the sandstone from these wells could be due to either profound chemical weathering of the rocks from the Cameroon highlands coupled with recycling of the older sandstones.

PETROGRAPHIC PLATES

PLATE 1



Qtz - Quartz, Fdp - Feldspar, Kyn - Kyanite, Ct - Cement,
Qo - Quartz overgrowth and Trm - Tourmaline.

Photomicrograph of Quartz arenite in well -B', 2440 - 2478m (cpl)
Mag. X200

PLATE 4

PLATE 2

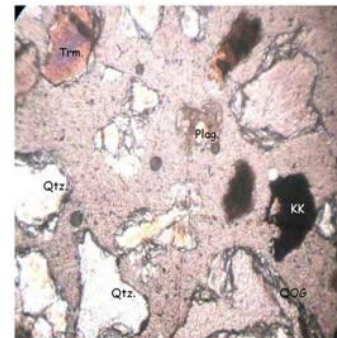


Qtz - Quartz, Diopd - Diopside, Fdp - Feldspar, Mf - Metamorphic rock fragment
and Ct - Cement.

Photomicrograph of Quartz arenite in well -D', 2530 - 2540m (cpl)
Mag. X20

PLATE 5

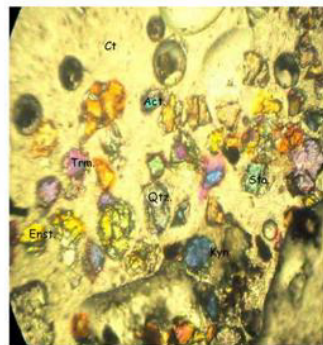
PLATE 3



KK- Iron stain, Trm - Tourmaline, Qtz - Quartz, Plag - Plagioclase and QOG - Quartz
overgrowth.

Photomicrograph of Quartz arenite in well -E', 2610 - 2655m (cpl)
Mag. X200

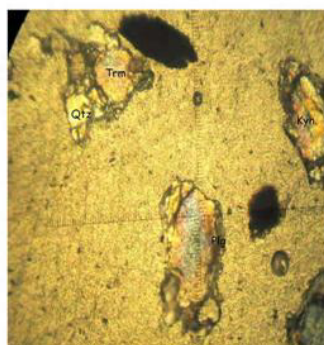
PLATE 6



Ent - Enstatite, Act - Actinolite, Stu - Staurolite, Trm - Tourmaline,
Ct - Cement, Kyn - Kyanite and Qtz - Quartz

Photomicrograph of Subarkosic in well -B', 3960 - 4000m (cpl)
Mag. X200

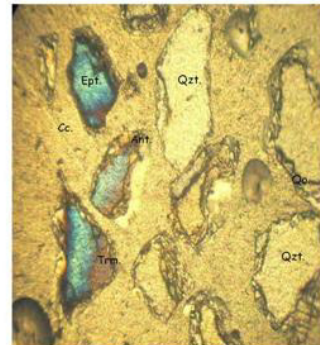
PLATE 7



Trm - Tourmaline, Qtz - Quartz, Plg - Plagioclase and Kyn - Kyanite

Photomicrograph of Subarkosic in well -D', 3825 - 3850m (cpl)
Mag. X200

PLATE 8



Ept - Epidote, Trm - Tourmaline, Qtz - Quartz, Ant - Anthophyllite, Cc - Calcite cement
and Qo - Quartz overgrowth

Photomicrograph of Subarkosic in well -E', 2200 - 2280m (cpl)
Mag. X200

PLATE 9



Ant - Anthophyllite, Ent - Enstatite, Stu - Staurolite, Qtz - Quartz and Plag - Plagioclase

Photomicrograph of Arkosic arenite in well -E', 3370 - 3400m (cpl)
Mag. X200



Ent - Enstatite, KK- Iron stain, Sept - Serpentine, Zr - Zircon, Fdp - Feldspar and Kyn -
Kyanite

Photomicrograph of Arkosic arenite in well -D', 3300 - 3320m (cpl)
Mag. X200



Ent - Enstatite, Qtz - quartz, Trm - Tourmaline, Fdp - Feldspar, Kyn - Kyanite and Act -
Actinolite

Photomicrograph of Arkosic arenite in well -D', 4110 - 4140m (cpl)
Mag. X200

Conclusion

The petrographic examination of the wells reveals the existence of three basic rock units within this study; these are quartz arenites, subarkosic and arkosic arenites respectively. However, the mineralogical composition showed that quartz is the pervasive mineral with minor occurrences of K-Feldspar, plagioclase and rock fragments. However, the percentage of plagioclase minerals within the slides was fair with negligible K-Feldspars minerals. The mineralogical maturity of the sandstone from these wells could be due to either profound chemical weathering of the nearby Oban Massif and granitic rocks of the Cameroon highlands coupled with recycling of the older sandstones. The analyzed minerals showed a good cementation materials and compacted pattern which reflect various episodes of their burial history. This analysis further showed that Zircon and Tourmaline minerals in association with the high mineralogical maturity within these sediments depict the provenance of igneous and metamorphic sources. Also an appreciable sign of abrasion was noticeable on the quartz grains as this explains the long transportation history of these sediments. The textural and mineralogical maturity of the sandstone implies that the sediments may have undergone more than one depositional cycle.

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